CLAIMS

What is claimed is:

1. A method of seismic surveying using vibrational seismic energy sources activated by sweep signals, the method comprising:
   (a) selecting a plurality of seismic energy sources to be used for surveying and a second number of sweep segments in excess of said first plurality;
   (b) selecting a third plurality of a highest order harmonic to be attenuated from processed data acquired using said seismic sources;
   (c) defining a sweep signal associated with each of said sources, each sweep signal comprising a plurality of sweep segments, each sweep segment of each seismic source having a determined phase;
   (d) driving each said source with its associated sweep signal to generate seismic waves propagating into the earth and recording a seismic signal in response thereto; and
   (e) processing said recorded seismic signal using a plurality of augmented signals associated with each seismic source to produce a processed plurality of processed seismic signals, each of said plurality of processed seismic signals associated with a different one of said seismic sources and having harmonics upto said selected third plurality attenuated.

2. The method of claim 1 further comprising determining said phase for each said segment of each said sweep signal, wherein said phase is determined by

(i) constructing a table with N rows and N columns, where N is the plurality of sweep segments, each entry $e_{H,M}$ being calculated from the formula

$e_{H,M} = hm$ modulo N,

where h is the row number and m is the column number;

(ii) selecting a number of columns equal to the number of sources such that the number in the first row of each selected column does not appear again in any selected column before the row H=F+1, where F is the highest order harmonic determined to cause significant crossfeed;

(iii) assigning a selected column to each seismic energy source, the initial phase angle for the hth sweep of that seismic energy source being represented by the number in the hth row of that column multiplied by $2\pi/N$;

3. The method of claim 1 wherein each said associated sweep signal comprises sweep segments, said sweep segments either concatenated or overlapping sequentially.

4. The method of claim 3 wherein each said augmented sweep signal further comprises said associated sweep signal and at least one of (i) a first sweep segment of said associated sequence, and, (ii) a final segment of said associated sequence.

5. The method of claim 1 further comprising measuring a level of the generated

seismic signal and using said level to adjust an amplitude of each of said other of said augmented signals prior to correlating said recorded seismic data.

6. The method of claim 1, wherein said sweep segments further comprise a sinusoidal wavetrain having a frequency that either increases monotonically with time or decreases monotonically with time.

7. The method of claim 6 wherein said increase or decrease of said frequency is linear with time.

8. The method of claim 1, wherein said sweep segments further comprise a psuedo-random sweep series.

9. The method of claim 8, wherein said pseudo-random sweep series are phase-rotated by selected increments.

10. A method for recording and processing vibratory source seismic data, the method comprising:

(a) generating a cascaded sweep sequence comprising N sweep segments that are either concatenated or overlapping sequentially, where N is equal to or greater than 2, said N sweep segments being substantially identical, except that the initial phase angles of said N sweep segments are progressively rotated by a constant phase increment of about $2\,m\pi/N$

radians where m is an integer and $|m|>1$;

(b) using said cascaded sweep sequence to drive a vibratory source thereby propagating a seismic wave into the earth at a selected location;

(c) recording a groundforce signal associated with said seismic wave,

(d) recording at least one reflection signal from a location within the earth responsive to said seismic wave, and

(e) using said recorded groundforce signal for processing the signal recorded to produce a processed signal.

11. The method of claim 10 wherein processing the signal recorded comprises cross-correlating the recorded signal with a signal comprising said groundforce signal and a first and a last sweep segment of said groundforce signal.

12. The method of claim 10, wherein said sweep segments further comprise a sinusoidal wavetrain having a frequency that either increases monotonically with time or decreases monotonically with time.

13. The method of claim 12 wherein said increase or decrease of said frequency is linear with time.

14. The method of claim 10, wherein said sweep segments further comprise a psuedo-random sweep series.

15. A method of seismic surveying using n vibrational seismic energy sources activated by sweep signals, the method comprising:

(a) selecting a number of seismic energy sources to be used for surveying;

(b) selecting a number of a highest order harmonic that has sufficient strength to cause significant harmonic distortion of a sweep segment that is part of a sweep sequence;

(c) defining a reference signal associated with each of said sources, each reference signal comprising a number N of sweep segments, N being greater than n, said sweep segments being either concatenated or overlapping;

(d) selecting initial phase angles for each sweep segment of each reference signal so that substantially all harmonics up to and including said highest order harmonic are suppressed and driving each vibratory source with its sweep sequence and driving each of said sources with its associated reference signal, thereby generating seismic waves propagating into the earth;

(e) recording ground force signals associated with each reference signal;

(f) recording at least one reflection signal from a location within the earth responsive to said seismic waves;

(g) using said n ground force signals for processing said at least one recorded reflection signal.

16. The method of claim 15 wherein processing said at least one recorded signal

comprises correlating the at least one recorded signal with a plurality of processing signals, each said processing signal comprising a reference signal combined with at least two segments of the reference signal.

17. The method of claim 15 wherein selecting initial phase angles further comprises:

(i) constructing a table with N rows and N columns, each entry e_{hm} being calculated from the formula $e_{hm} = h\,m$ modulo (N) where h is the row number and m is the column number;

(ii) selecting a number of columns equal to the number of sources such that none of the numbers of each selected column appears again in any other selected column before the row $H = F+1$, and

(iii) assigning a selected column to each seismic energy source, the initial phase angle for the h-th sweep segment of that seismic energy source being represented by the number in the h-th row of that column multiplied by $2\,\pi/N$.

18. The method of claim 15, wherein said sweep segments further comprise a sinusoidal wavetrain having a frequency that either increases monotonically with time or decreases monotonically with time.

19. The method of claim 18 wherein said increase or decrease of said frequency is linear with time.

20. The method of claim 15, wherein said sweep segments further comprise a psuedo-random sweep series.

21. The method of claim 20, wherein said pseudo-random sweep series are phase-rotated by selected increments.

22. A method of conducting *n* seismic surveys simultaneously at substantially the same location where *n* is an integer, the method comprising:

(a) simultaneously transmitting with *n* vibratory sources associated groundforce signals into the earth, each said groundforce signal including a fundamental signal and harmonics thereof, said fundamental signal having an initial phase;

(b) recording said *n* groundforce signals;

(c) recording at least one reflection signal from a location within the earth responsive to said plurality of groundforce signals to give a first recorded signal;

(d) repeating steps (a) - (c) *m-1* times wherein said initial phases are shifted by $2\pi/m$ radians to give a total of *m* recorded signals and *n* x *m* groundforce signals;

(e) using the *n* x *m* ground force signals for processing the *m* recorded signals to give processed signals associated with each vibratory source.

23. The method of claim 22 wherein processing the *m* recorded signals further comprises:

(i) correlating the first recorded signal with each of the associated ground force signal to give *n* intermediate signals;

(ii) repeating step (i) m-1 times to give a total of *n* x *m* intermediate processed signals;

(iii) summing the *m* intermediate processed signals associated with each vibratory source to give a processed signal associated with each vibratory source.

24. The method of claim 23, wherein said sweep segments further comprise a sinusoidal wavetrain having a frequency that either increases monotonically with time or decreases monotonically with time.

25. The method of claim 24 wherein said increase or decrease of said frequency is linear with time.

26. The method of claim 22, wherein said sweep segments further comprise a psuedo-random sweep series.

27. A method of seismic surveying using vibrational seismic energy sources activated by sweep signals, the method comprising:

(a) selecting a number of seismic energy sources to be used for surveying;

(b) selecting a number of a highest order harmonic that has sufficient strength to cause significant harmonic distortion of a sweep segment that is part of a sweep sequence;

(c) selecting a number of sweep segments in excess of the number of seismic energy sources used;

(d) selecting initial phase angles for each sweep segment of each seismic energy source so that substantially all harmonics up to and including said highest order harmonic are suppressed, the step of selecting initial phase angles further comprising:

(i) constructing a table with N rows and N columns, where N is the number of sweep segments, each entry $e_{H,M}$ being calculated from the formula

$e_{H,M} = hm$ modulo N,

where h is the row number and m is the column number;

(ii) selecting a number of columns equal to the number of sources such that the number in the first row of each selected column does not appear again in any selected column before the row H=F+1, where F is the highest order harmonic determined to cause significant crossfeed;

(iii) assigning a selected column to each seismic energy source, the initial phase angle for the hth sweep of that seismic energy source being represented by the number in the hth row of that column multiplied by $2\pi/N$;

(e) generating a first sweep sequence associated with each energy source, consisting of sweep segments having initial phase angles obtained in step (d), said sweep segments being either concatenated or overlapping sequentially;

(f) driving each of said energy sources using one of its associated sweep sequences thereby generating a seismic signal which propagates into the earth;

(g) recording uncorrelated seismic data resulting from reflection of said seismic signal from subterranean geologic formations;

(h) combining the portion of said uncorrelated seismic data recorded during a first sweep segment with said recorded uncorrelated seismic data recorded during a 'listen time,' to form a combined uncorrelated seismic data record;

(i) correlating said combined uncorrelated seismic data record with each of said first sequences to give correlated data associated with each of said energy sources.

28. The method of claim 27 further comprising measuring a level of the generated seismic signal and using said level to adjust an amplitude of each of said other of said cascaded sweep sequences prior to correlating said combined recorded seismic data.

29. The method of claim 27 wherein said sweep segments further comprise a

sinusoidal wavetrain having a frequency that either increases monotonically with time or decreases monotonically with time.

30. The method of claim 29 wherein said increase or decrease of said frequency is linear with time.

31. The method of claim 27, wherein said sweep segments further comprise a psuedo-random sweep series.

32. The method of claim 31, wherein said pseudo-random sweep series are phase-rotated by increments chosen by the method of claim 27 (d).

33. A method of seismic surveying using a vibrational seismic energy source activated by sweep signals, the method comprising:

(a) selecting a highest order harmonic that has sufficient strength to cause significant harmonic distortion of a sweep segment that is part of a sweep sequence;

(b) selecting a plurality of sweep segments and initial phase angles for each sweep segment so that substantially all harmonics up to and including said highest order harmonic are suppressed,

(c) generating a first sweep sequence associated with each energy source, said sweep segments being either concatenated or overlapping sequentially;

(d) driving said energy source using the sweep sequence thereby generating a seismic signal which propagates into the earth;

(e) recording uncorrelated seismic data resulting from reflection of said seismic signal from subterranean geologic formations;

(f) combining the portion of said uncorrelated seismic data recorded during a first sweep segment with said recorded uncorrelated seismic data recorded during a 'listen time,' to form a combined uncorrelated seismic data record; and

(g) correlating said combined uncorrelated seismic data record with said sequence to give correlated data.

34. The method of claim 33 wherein selecting said initial phase angles further comprises:

(i) constructing a table with N rows and N columns, where N is the number of sweep segments, each entry $e_{H,M}$ being calculated from the formula

$e_{H,M} = hm$ modulo N,

where h is the row number and m is the column number;

(ii) selecting a number of columns equal to the number of sources such that the number in the first row of each selected column does not appear again in any selected column before the row H=F+1, where F is the highest order harmonic determined to cause significant crossfeed;

(iii) assigning a selected column to each seismic energy source, the initial phase angle for the hth sweep of that seismic energy source being

represented by the number in the *h*th row of that column multiplied by $2\pi/N$;

35. The method of claim 33 further comprising measuring a level of the generated seismic signal and using said level to adjust an amplitude of each of said other of said cascaded sweep sequences prior to correlating said combined recorded seismic data.

36. The method of claim 33 wherein said sweep segment further comprises a sinusoidal wavetrain having a frequency that either increases monotonically with time or decreases monotonically with time.

37. The method of claim 36 wherein said increase or decrease of said frequency is linear with time.

38. The method of claim 33, wherein said sweep segments further comprise a psuedo-random sweep series.